manifold. It is critical to protect the manifold from contamination due to the difficulty of cleaning and decontamination. In some systems, a portion or most of the cleaned or treated exhaust gas may be recirculated back to the gloveboxes.

[Note: The manifold system should be sized and controlled to accept a range of flow whose high extreme is the sum of (1) the maximum normal flow from each box (Sections 7.2.1, 7.2.2, and 7.2.3), (2) the largest maximum flow under removed glove conditions from one of each of five connected boxes (Section 7.2.4), and (3) an allowance for system growth. The low extreme is the sum of the minimum flows from each box. An allowance for system growth should be provided at not less than 20 percent of (1) plus (2) above for a new system. If this allowance exceeds 50 percent of (1) plus (2), other provisions such as installing an equivalent dummy flow should be considered.

7.2.9 EXHAUST CLEANUP REQUIREMENTS

As Low as Reasonably Achievable (ALARA) exposure to radioactive material is the guiding principal for determining the design of a glovebox ventilation unit. Protecting the exhaust downstream of the primary HEPA filter is paramount for nuclear installations. Experience has shown that exhaust systems are not only difficult to decontaminate, but have led to operator exposures. It is also true that, after filter breakthrough, nuclear particles can migrate to all the gloveboxes in the chain. As discussed earlier in this chapter, a filter installation is only as good as the entire ventilation system.

When corrosive gases or vapors are in the exhaust airstream, all of the filters in a series will be exposed. The widely held impression that the life expectancy of a group of HEPA filters arranged in series is directly proportional to the number of filters in the series may be false when chemical or heat degradation occurs. Under these conditions, when the first stage fails, there is a potential for others to fail from the same cause. Corrosive gases and mists from vats, scrubbers, and similar equipment must be neutralized and removed before they reach the HEPA filters.

Installation requiring redundant HEPA filters must have provisions for in-place testing. The requirements are provided in ASME N-510[32] and ASME AG-1, Section TA.[29] If chemical detection systems are required due to possible filter installation damage, the monitoring system should be HEPA-filtered to prevent damage to the instrument. Many manufacturers supply testable filters of this type. These should be specified with upstream and downstream test ports. The filter flow should be consistent with the monitoring instrument airflow.

7.3 GLOVEBOX FILTER INSTALLATIONS

For the most part, the glovebox filter systems discussed in this section are first-stage (primary) HEPA filters, although redundant filters located upstream from the exhaust manifold (if equipped) connection are also discussed.

Filters must be able to perform properly when they are either clean or dirty. A maximum dirty-filter resistance of three times the clean-filter resistance for HEPA filters and two times the clean-filter resistance for prefilters is generally used for design purposes. **FIGURE 7.5** gives the approximate airflow and pressure-drop relationships for clean open-face HEPA filters. **FIGURE 7.6** shows common locations for HEPA filters near or inside gloveboxes. Type 2C shows the installation of inlet and exhaust filters inside the glovebox.

7.3.1 HEPA Filters

A detailed discussion of filter performance and construction materials is given in Section 3.2.

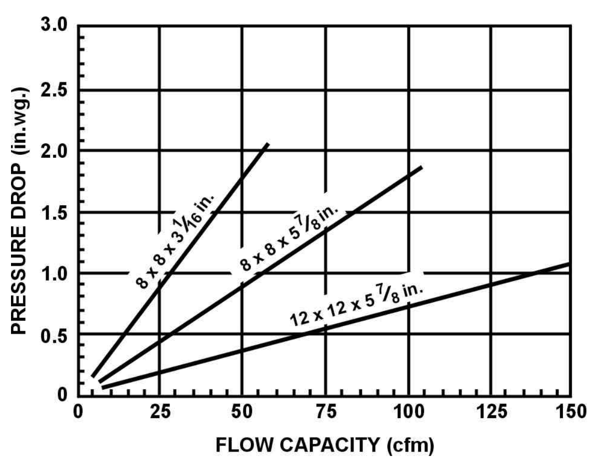

Figure 7.5 – Flow vs. pressure drop relationship for small, clean, open-face HEPA filters

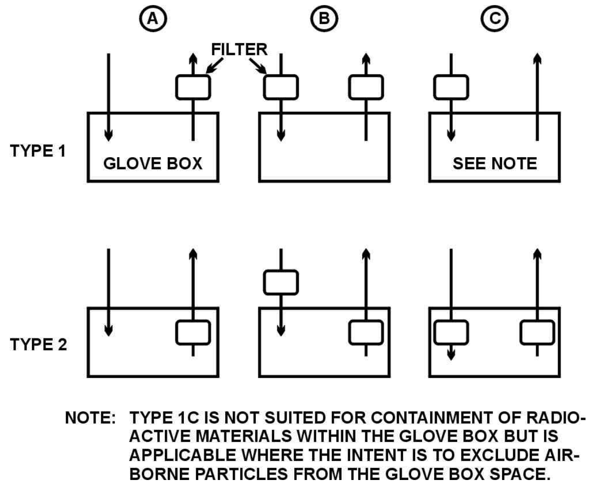

Figure 7.6 – Possible arrangements of filters near or inside glove boxes

Operational experience with a particular system is the most reliable basis for filter selection for a particular service. For new and untried systems, the initial choice should be limited to the traditional site-specific, open-face pleat and constructed to the requirements of Section 3.2. These filters should also meet the requirements of ASME AG-1. If exhaust streams are kept chemically neutral, as they should be for reliable exhaust-system operation, HEPA filters of standard construction usually afford the most economical service.

A single-HEPA-filtered exhaust path is defined as a glovebox that does not involve highly toxic aerosols or potent, toxic, or radioactive materials. These are materials that do not pose a hazard to the operator during a filter change-out. A multiple-filtered exhaust path is defined as a glovebox requiring more than one line of defense from particle penetration. This occurs when the exhaust ductwork or manifold must be protected or the MPPS (Most Penetrating Particle Size) is well below the efficiency particle mean of the filters.

When continuous airflow is essential, two exhaust connections should be provided to avoid interruption of exhaust flow during a filter change and to provide standby protection in the event of system upset. The purpose of multiple exhaust connections is to allow an emergency connection to be made. **FIGURE 7.7** illustrates single-and multiple-filtered exhaust connections for a glovebox.

Multiple-filtered exhaust connections should be used when interconnected gloveboxes or when a large enclosure with several compartmented work areas are needed. Compartmenting doors between work areas or between single boxes in an interconnected line must not isolate a work area with only one filtered exhaust connection. The multiple exhaust points required to handle total airflow in a line of interconnected boxes must be sized for maximum flow and valved individually for flow control. DOE STD 1066-99[30] discourages the use of long lines of interconnected gloveboxes for fire control. Where they are necessary, fire doors between the gloveboxes should be provided. This would necessitate the use of proper alarming and resolution of pinch-point concerns.

The glovebox designer should understand the limitations imposed by ergonomics. There is an art to the design of the glovebox, ventilation service, and internal equipment operation and service. Some facilities build mockups of the glovebox concept to determine whether the operations can be done in a practical manner. It is critical to prove the practicality in some operator-intensive, hands-on operations and long-term production activities. It is better to demonstrate the activities at the design phase than to wait for the glovebox to be built. Failure to do this can be very costly to repair or can be a great compromise to the safety of the operator.

Tasks performed within the confines of a glovebox should factor in the weight of the objects handled and the location of the operation(s) to be performed within. Experience has shown that operators may at first pick an item off the floor of a glovebox to prevent scratching the floor, only to find later that the item is now being dragged across the floor. The floor is now scarred making it difficult to clean. The fatigue factor is high when working in a glovebox. The working pressure, heat, glove sleeves, glove port location, and operations where the arms are outstretched all add to the fatigue factor. Intricate or sensitive work significantly adds to the fatigue factor because the operator simply cannot feel through gloves. If visibility is poor or nonexistent, the operation will be very difficult, if

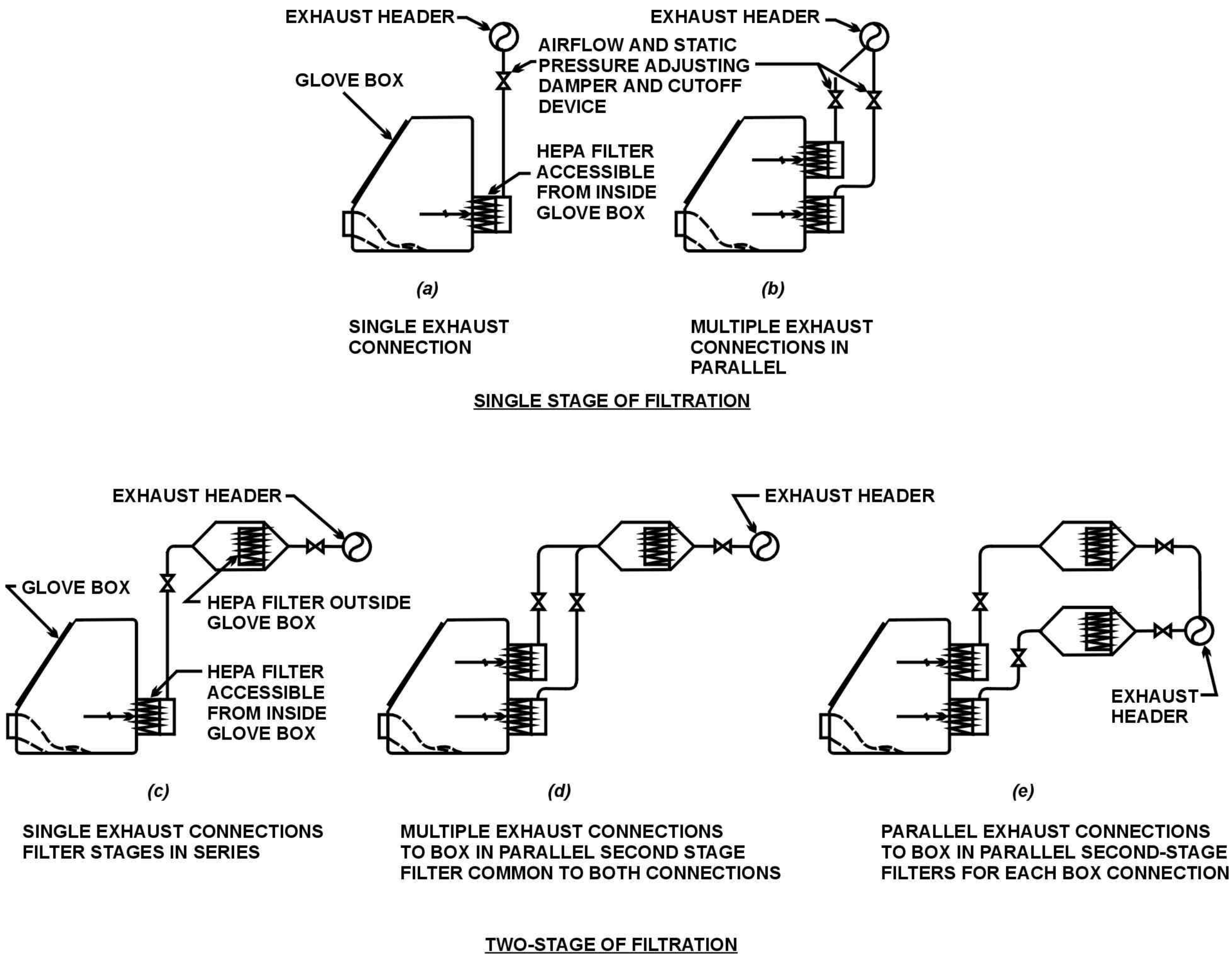

Figure 7.7– Suggested arrangements for single- and parallel-filtered exhaust connections for glove boxes

not impossible, to perform. Some operations with older gloveboxes used mirrors to perform some operations. It should be noted that this was done out of necessity due to poor design or a compromise with some other activity. Extended reach, in glovebox terms, is used to describe an occasional operation where something is pulled forward to a working position or a simple operation such as turning a switch off or on. In this context, it may be lowering or pulling out a spent filter for disposal. Extended reach should be avoided in repetitive or routine operations.

7.3.2 HEPA Filter Selection Criteria

HEPA filters are available in many configurations for many applications. For most applications, glovebox HEPA filters are customized for to meet industry needs. Many of the different filter housings described earlier are intended for nuclear and non-nuclear service. These filter housings use different sized filters with different types of seals. Filter selection should be based on airflow requirements and efficiency requirements. Airflows for worker protection, fumes venting, and cooling are discussed in this chapter. The efficiency of HEPA filters is discussed in Chapter 3. Another variable to application is efficiency. Selecting a more efficient filter for an application may be necessary to prevent particle bypass through a standard HEPA filter. The higher efficiency filters are called ULPA or VLSI filters (described in Section 3.1.1). There are materials in use that have a greater amount of small particles below the most penetrating particle size (MPPS) for HEPA filters. These materials simply bypass a HEPA filter and migrate into the ductwork. Redundant filters can sometimes be used for these applications, however, this assumes that the area between the filters can be cleaned.

Several of the characteristics listed below are typical of the installations at many nuclear sites throughout the United States.

- Uses a standard-size HEPA filter located in the back- or end-wall of the glovebox.
- Maximizes inside box space by partially recessing the filter in the wall.
- Has a simple clamping method with no removable pieces and is operable with a gloved hand by a simple, clean clamping mechanism.
- Has a retainer that serves as a face shield for the filter and permits attachment of a steel-cased prefilter by a flexible magnetic strip (accessible from the front); the filter remains in position after being unclamped because of the folded lip at the top.

Table 7.1 – Glovebox Bag-Out Port Sizes for Transfer of Standard Open-Face HEPA Filters

Filter size	Required port size (in.)	
	Round (diameter)	Rectangular
8 × 8 × 2 1/16	9 3/4	8 1/2 × 4 1/2
8 × 8 × 5 7/8	10 3/4	8 1/2 × 6 1/2
12 × 12 × 5 7/8	14	12 1/2 × 6 1/2
24 × 24 × 5 7/8	26	25 × 6 1/2
24 × 24 ×11 1/12	27 3/4	25 × 12

7.3.3 PREFILTER SELECTION

Prefilters are used to protect the more expensive HEPA filters located at the inlet and exhaust filter housings. These filters are disposable and should be routinely changed when they are loaded and affect the ventilation system. This can be determined by noting the sensitivity of glove movement and pressure recovery. In easily airborne powder applications where a significant amount of dust is airborne in a glovebox, removing the prefilter may be the only means to restore safety (negative pressure) to the glovebox during a powder mishap. Prefilters for gloveboxes come in a range of sizes and configurations. Some facilities use simple cut, in-place pads, and some use HEPA filters (not tested) to perform the prefilter function. This has been application-, site-specific-, and retrofit-driven. For some applications where air entering the glovebox is HEPA-filtered and there is little or no dust loading in the glovebox, an exhaust prefilter may not be needed. A prefilter should be considered on the inlet HEPA filter on the glovebox unless the glovebox resides in a cleanroom. Prefilters are manufactured from a fiberglass media similar to the HEPA filters. As a result, they are susceptible to the same chemicals, fumes, and heat damage. Some prefilters are manufactured with a beverage board (coated cardboard) frame and should be avoided if fire is a concern.

Prefilters are typical of the type referenced in Section 3.4 as Group I panel filters. The main advantage is cost, quick installation, and removal. There is a distinctive ergonomic advantage. These filters are pushed into a channeled frame instead of tucked into and around a frame—a difficult operation when the exhaust filter is ceiling-mounted. Use of a separate removable frame is preferable in these applications. It also should be noted that the ability to perform this operation should be based on either a mockup or an existing glovebox installation.

Prefilter holding devices should be manufactured from the same material as the glovebox or a material that is resistant to the chemicals and fumes that will be present in the airstream. Retaining fasteners, when used, should be made of dissimilar materials that do not gall. It is better to dispose a 302 sst wing nut than to replace a 304-L sst stud welded on a glovebox. The frame should be designed to minimize air bypass around the prefilter, yet allow enough clearance between the HEPA filter and prefilter to prevent media contact. An independent holding frame should be incorporated in the design to prevent disturbing another filter installation.

7.3.4 INLET HEPA FILTERS

Work performed in gloveboxes frequently requires supply air to be kept free of airborne contaminants. Inlet HEPA filters help maintain clean conditions inside and, when chosen properly, also serve three other useful functions: (1) extending the service life of the exhaust filter by protecting them from atmospheric dirt loading, (2) preventing the spread of contamination from the glovebox to the room in the event of a glovebox pressure reversal, and (3) providing overpressure relief.

The design of the inlet filter installation is relatively simple for air-ventilated nonrecirculating gloveboxes. Since no duct connections are required, open-face filters may be used with an installation and clamping method that leaves one face completely exposed. Typical methods of installation are shown in **FIGURES 7.8 and 7.9.** Because they are less likely to be contaminated, inlet air filters are easier to replace than exhaust filters; therefore, they provide fewer problems and less risk during changes. Whether mounted inside or outside the glovebox (outside mounting is preferred), the same high quality mounting, clamping, and sealing are required.

The open face of the filter must be protected from physical damage and fire. Plugging of the inlet filter by smoke is of secondary concern, however, since one recommendation for glovebox fire suppression is to reduce normal airflow. Locating the inlet connection (or an attached inlet duct) high in the box tends to reduce the amount of air drawn into the box during a fire because of the chimney effect.

7.3.5 HEPA FILTER SELECTION

The number of types and sizes of HEPA filters used at an installation should be minimized for logistical and operating economy. All HEPA filters should be of fire-resistant construction. The sizes of HEPA filter used in glovebox systems vary, with square 8- × 8- × 3 1/16-in., 8- × 8- × 5 7/8-in., and 12- × 12- × 5 7/8-in. sizes and nominal airflow capacities of 25, 50, and 125 cfm, respectively. Glovebox filters should be operated at their design airflow. Wood-cased fire-resistant HEPA filters are less expensive and should be considered wherever the operating environment (temperature, humidity, etc.) permits. Most applications use 304 and 304-L stainless steel due to the robust nature of the casing and the chemical, fire, and humidity requirements. The "cartridge," as noted in Section 7.2, comes in a round configuration with an 8-in. diameter.

Undesirable features of both the enclosed and open-face HEPA filters include:

- Capacities are insufficient for large amounts of dust.
- Chemical fumes such as caustic hydrofluoric acid mist can destroy filter medium separators and adhesives.
- Sharp corners and edges of metal casings can damage protective bagging.
- In dry atmospheres (less than 217r, RH) the plywood of wood-cased HEPA filters may shrink and delaminate, causing eventual failure of the filter. Very low moisture levels may cause a shrinkage problem for particleboard casings as well. This could be an acute problem in inert atmospheres where very low moisture levels (less than 50 ppm) have to be maintained. In such systems, steel-cased filters should be used.

Open-face HEPA filters have the following additional shortcomings:

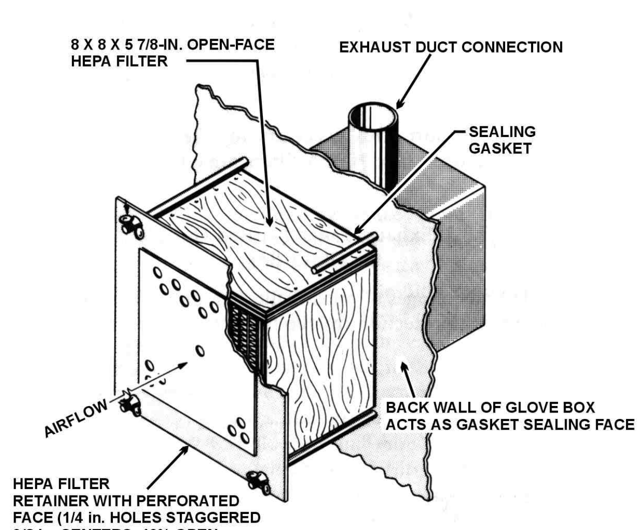

Figure 7.8 – Open-face filter installation method (a)

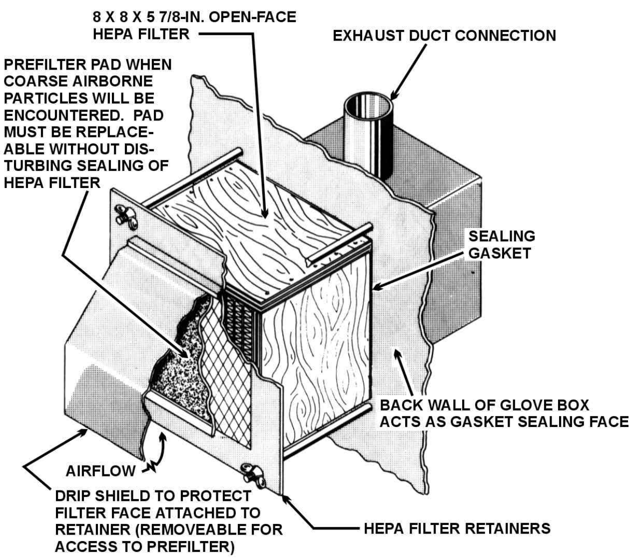

Figure 7.9 – Open-face filter installation method (b)

- They are more vulnerable to damage during handling and storage.
- They lack a handle or gripping area for ease of withdrawal from an enclosure.
- It is difficult to replace damaged face gaskets.

Enclosed HEPA filters have the following additional shortcomings:

- They lack Underwriters Laboratories (UL) certification.
- Reeding (induced vibration of separators caused by air motion) at high flow rates is worse than in open-face filters because the entering air impinges on a smaller area of the filter pack;
- Their weight is greater than that of open-face filters.
- They cost substantially more than open-face filters.
- They have greater space requirements.
- There is an air leakage problem with steel cases, especially in inert-atmosphere and high-pressure applications.
- There are no visible means of detecting damage to the medium.

7.3.6 PREFILTERS

As in larger systems, prefilters may be used in both the inlet and exhaust air streams to extend the life of the HEPA filters used in glovebox filtration systems. Prefilters are sacrificial items, and the decision to use them requires the designer to evaluate the advantage of longer HEPA filter life against the problems of limited space frequently encountered in glovebox systems. Prefilters attached directly to the face of the HEPA filter provide no fire protection for that HEPA filter. Glovebox prefilter service often requires filters to be subjected to periods of high temperature, moisture, dust, and corrosive agents that shorten their effective life and mounting.

Experience with prefilters in glovebox ventilation systems has shown the use of metal media to be impractical. Without viscous coatings, the filtering efficiency of metal-media prefilters is poor, and these filters are often almost impossible to clean and decontaminate. Adhesives and oil coatings that improve particle retention reduce in-box cleanness and fire resistance. Experience clearly indicates that using conventional types of prefilters that require cleaning or decontamination or both before reuse is impractical. Throwaway filters with simple installation methods are preferred. After use, the units are discarded as contaminated waste unless collected materials must be reclaimed. Glass-fiber-media prefilters are preferred because serviceability is good, costs are low, and combustible content is small.

Inlet airstreams with HEPA filters should be fitted with prefilters when using atmospheric air. However, when the room air has been cleaned of the bulk of its airborne dust by building supply-air systems, when local room activities do not generate dust and lint that can be drawn into the box, and when airflow through the HEPA filter is less than 75 percent of its rated capacity, there may be no need for a prefilter.

A common method of prefiltering is to clip a thin (1/8- to 1/4-in.) fiberglass pad to both the inlet and exhaust HEPA filters, as shown in **FIGURE 7.10**. Neither plastic foam nor organic fiber should be used because both are flammable. The pad is cut to fit the face of the HEPA filter and is clipped to the filter retainer. This method of attachment permits easy removal of the prefilter pad without disturbing the seal of the HEPA

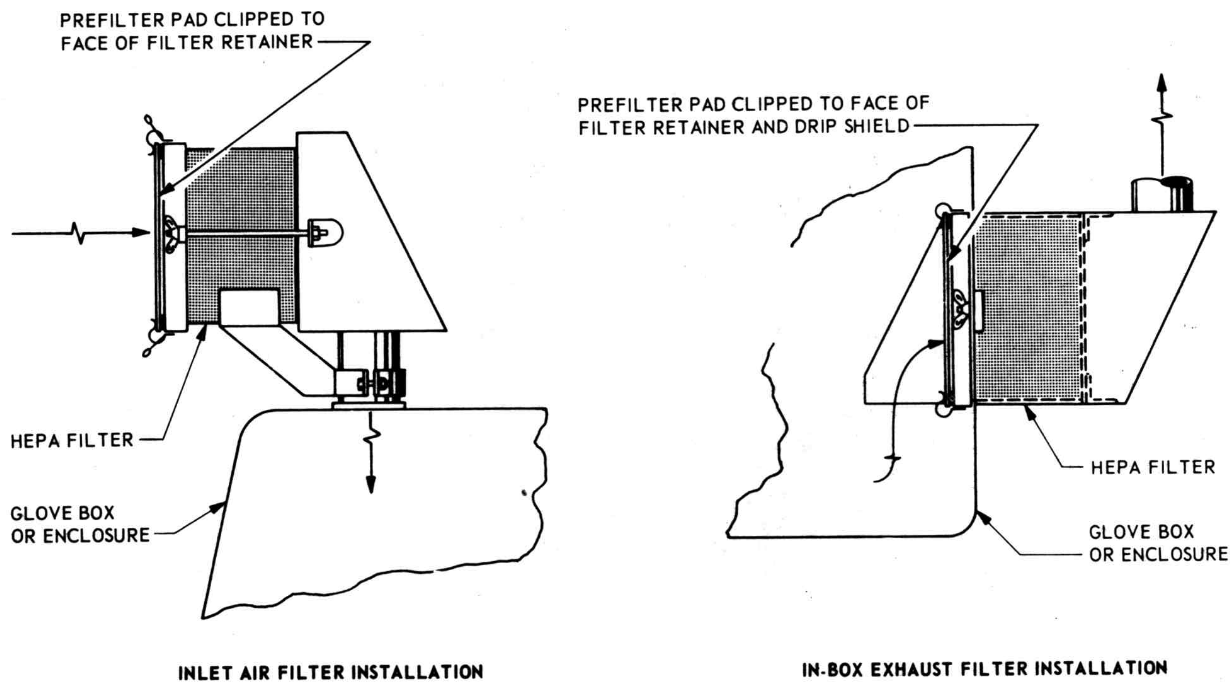

Figure 7.10 –Typical installation of prefilter pads on face of HEPA filters

filter. Normal usage generally requires frequent replacement of the prefilter pads, which do not have much dirt-holding capacity and can quickly become plugged by house dust and lint. Convenient methods of attaching the prefilter pads are essential to simplify the operations performed inside the glovebox. Frequent replacement of prefilter pads provides the following benefits:

- Air resistance (pressure drop) does not change rapidly, which allows airflow to remain more constant without frequent manipulation of airflow dampers.
- Accumulation of combustible dust in the exhaust path is lessened, thereby providing better fire protection for the HEPA filter downstream if the prefilter is not applied directly to the face of the HEPA filter;
- The exhaust path can pass a greater airflow when relieving an emergency condition.

Thin fiberglass pads (1/4-in. thick or less) can provide average atmospheric dust collection efficiency up to 20 percent with low airflow resistance. Thin, clean fiberglass pads used at air velocities of 35 fpm will create an initial pressure drop in the range of 0.03 to 0.15 in.wg. Chapter 3 lists several types of media that can be used as prefilter pads. For applications where long-term continuous processes hamper regular maintenance of in-box filters, the designer must include the following provisions:

- Greater suction pressure (well below the limit that would subject glove or box integrity to unsafe differential levels) controlled by the damper to allow longer use of prefilters
- Larger prefilters
- Selection of a prefilter with less initial resistance to permit longer use, even with lowered collection efficiency

7.3.7 ROUGHING FILTERS

In some installations it is desirable to be able to recover material from the filters for either reprocessing or waste minimization. Roughing filters may be used for this purpose. The filter media is typically less efficient than that of the HEPA filter. Materials of construction may be suitable for the recovery process (Category 3 - combustion, acid dissolution, etc.), but must not present a hazard to the downstream prefilter and HEPA filters. Firescreens, etc., shall be used to prevent roughing filters from impacting downstream prefilters or HEPA filters.

7.4 FILTER REPLACEMENT

The safe replacement of a contaminated glovebox filter must be planned in the design phase to facilitate proper execution. The filter change method and other maintenance functions, if other than site-specific, should be determined and planned. The designer should prepare a written preliminary filter change procedure along with the design documents. If the design is questionable due to an extreme custom nature, the glovebox should be mocked up so that an operational demonstration can be performed. It should be noted that special tools used to perform filter and maintenance operations in the part were employed out of necessity and should be avoided, if possible. In applications where controlled inert atmospheres are present, filter changes should be planned for times when other routine or special maintenance operations are taking place inside the box to reduce interruptions to operations and loss of inert gas, and to minimize the time required to reintroduce the inert gas into the box spaces.

The operational team directly involved in a filter change-out must wear appropriate respiratory protection, as specified by site-specific requirements. Filters installed inside the glovebox are accessible via the gloves on the glovebox. When the total activity of contaminants is high, additional protective measures may be necessary to reduce worker exposure. One of the safest and most common methods for preventing the spread of contamination while maintaining containment is bagging the filters in and out of the glovebox. The plastic bagging materials used are discussed in Section 6.2.3. When inert-atmosphere or oxygen-free environments are used inside the glovebox, additional provisions may be required to prevent air leakage into the box.

Replacement of a HEPA filter inside an air-ventilated box entails many steps that must be performed sequentially. The Standard Operating Procedures must be written and the team must be trained to perform the operations in a safe, controlled manner. Close coordination between maintenance and operating personnel is necessary to establish a mutually satisfactory date and time for the filter change, to identify the boxes and systems involved, to procure the necessary materials, and to schedule personnel. The health and safety requirements of the industrial hygienist, health physicist, and safety engineer must be established. One of these specialists should be designated the health and safety supervisor and should be available to monitor the operation and assist as necessary.

When the necessary materials and tools are ready and all personnel have been instructed in their specific duties, final permission must be secured from the responsible operator to alter the airflow and replace the filters. The flow path of the exhaust system should be thoroughly understood, and persons responsible for the related exhaust systems that will be affected should be forewarned. For instance, if two glovebox exhaust systems manifold to the same blower, final filters, and stack, the removal of one system from service for a filter change will affect the system flow and pressure characteristics of the other system. Safety clothing and respiratory protection should be worn as directed by the health and safety supervisor. Typical steps required to change a filter and place a box back in service include the following:

1. Cease all glovebox operations and contain unsafe materials in suitable containers.
2. Cut off gas flow to the glovebox affected, and adjust flow through the remaining branches to restore a safe negative pressure and flow rate in each.
3. Bag a clean replacement filter (and prefilter if used) in a small, clear plastic bag with sufficient tape to hold the spent filter and prefilter with all of the hand tools required, as shown in steps A, B, and C of **FIGURE 7.11**. It is recommended that the hand tools needed for filter changing be introduced the first time the filters are changed, and then left in the glovebox for subsequent use if space and environment permit. Decontamination is often more costly than tool replacement.
4. Using the glovebox gloves, remove the dirty filter and prefilter from their mounting frame.
5. Insert the dirty filter and prefilter into an empty plastic bag along with any residual